Exploring the Use of Microworld Models to Train Army Logistics Management Skills

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PREFACE

This report provides the results of a study to assess the effectiveness of using microworlds to train Army logisticians. This study was conducted as part of a larger project to design training for a new logistics organization, the Theater Support Command. The work was sponsored by the U.S. Army Combined Arms Support Command. It should interest both those who are involved with military logistics and those involved with training and education.

The project was carried out in the Manpower and Training Program of RAND Arroyo Center, a federally funded research and development center sponsored by the United States Army.

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BACKGROUND

The Army faces new challenges in training its logistics managers. As the Army evolves into a force-projection Army, the design and management of large-scale logistics systems assume increasing importance. However, these skills are difficult to train, because large deployments occur infrequently and thus opportunities to design and manage systems also occur infrequently. Furthermore, most of the people who work in high-level logistics management organizations are in the Army Reserve, and they train and practice their skills part time. Also, reserve units tend to be spread across large geographic areas, which makes it difficult to regularly train complete units at one time. Finally, the reserves experience considerable turnover in personnel, which poses a formidable challenge to maintaining continuity and creates a constant demand to train new members. The Army's ongoing revision of its logistics doctrine exacerbates these challenges.

A DIFFERENT APPROACH

The Army needs a way to come to grips with these training challenges. One approach, the use of microworlds, offers a potential solution. A microworld is a computer-based learning tool that enables an individual to interact with a specific environment much in the way that a flight simulator enables a pilot to practice a wide range of aerial maneuvers. Microworlds can teach both content and process.

RAND has successfully employed microworlds to teach complex academic skills. That experience, combined with the work of others, led RAND researchers to hypothesize that microworlds could assist the Army with its problem of training logistics design and management. Specifically, it appeared feasible for microworlds to simulate a dynamic theater-level management-distribution system that could both enable exploratory learning (i.e., discovering what kinds of problems will crop up) and train on-the-job skills. Such a capability would offer many advantages. It could be used to train new members without waiting for infrequently conducted large-scale exercises; it could also be used for interunit exercises conducted in several different locations simultaneously using the Internet. The microworlds would be far less expensive and more flexible than large-scale simulations that run on mainframe computers.

One problem is that we have little empirical data on the effectiveness of using microworlds to teach complex management skills. Demonstrating such effectiveness is difficult, but before the Army invests in microworlds, it would be prudent to determine whether they can provide the expected benefits.

THE STUDY

To provide such a demonstration, RAND developed a quasi-experimental procedure to test the effectiveness of using microworlds to train soldiers in the design and management of logistics systems. The study was conducted as part of a larger RAND Arroyo Center effort to design training for an emerging Army organization, the Theater Support Command, and one of its subordinate elements, the Distribution Management Center.

The study consisted of a three-hour curriculum built around a microworld model that simulates a simplified version of a distribution management process. Sixty-five Army reservists from theater-level distribution management organizations participated in training and demonstration sessions and then completed a skills assessment. The training and assessment approach included several features designed to test the effectiveness of the microworld-based curriculum strategy while minimizing threats to validity. However, no comparison was made between the microworld-based training and other training methods on either a cost or effectiveness basis.

THE RESULTS

The results indicate that microworlds can effectively train complex management skills. We used two categories of measures to determine the effects of the training: objective and subjective.

Objective Measures

On average, after training, participants were able to identify more problematic trends in data than they were before training. Improvements in identifying the effects of the trends were smaller but still significant. We examined the effects of a number of variables on the test results: (1) outcome measures, (2) experimental control variables, and (3) demographic variables. None correlated even moderately with the change from pretest to posttest; however, a few correlated with pretest performance, posttest performance, or both.

Subjective Measures

The subjective measures mirrored the objective ones. Participants believed that their understanding of key concepts related to distribution management increased during the course of the three-hour training session. Specifically, they reported increases in their understanding of how to measure a theater distribution system, how to evaluate alternative distribution policies, the effects of policies over time and on other organizations, and how to manage a general supply distribution network.

OBSERVATIONS

Most worthy of note in this study is the finding that the use of microworld training led to significant improvement in identifying trends in data and in analyzing the effects of those trends. This is particularly significant because the test environment was challenging, and the learning of a substantial amount of material took place in a short time. Of the three hours, only about one hour was devoted to time on the task. The rest was devoted to introductory material, assessments, and an explanation of the mechanics of the microworld model.

Should microworld-based curricula continue to demonstrate promise, a number of directions should be pursued to support their use. First, a reusable library of scenarios that can be assessed via networks should be developed. Also, having network-based access to microworld curricula (e.g., via the World Wide Web) would enable collaborative training. Microworld-based training seems to offer considerable promise for training the sorts of complex management skills needed by logistics system designers and managers.

ACKNOWLEDGMENTS

The authors appreciate those who have helped throughout this project. George Park produced our first prototype microworld model, and Joy Moini helped produce the training and testing materials. John Winkler and Henry (Chip) Leonard provided helpful reviews of an earlier draft, and Shirley Cromb provided excellent secretarial support. We also benefited from the critiques of our initial ideas and findings by RAND colleagues and by J. Michael Polich, our program director. Thomas Edwards, Deputy to the Commander, U.S. Army Combined Arms Support Command (CASCOM), and Bruce Schoch, Training Directorate, CASCOM, have provided their insights on the direction and applicability of these tools.

The soldiers of the 310th Theater Support Command (TSC) were a good training audience and provided helpful suggestions for improving our prototypes. MG Thomas Plewes, then Commanding General of the 310th TSC, was a key person in conducting this research. His foresight concerning the potential benefits to the Army provided the opportunity to interact with a training audience of sufficient size and focus to conduct a meaningful assessment. His successor, BG David Kaucheck, continued to support our efforts. Several staff officers of the 310th TSC were instrumental in our ability to execute the entire training program throughout the unit's training year: COL Margaret Tankovich, COL James Roland, COL Michael Wermuth, COL Collis Phillips, LTC Michael Avakian, LTC Patrick Cathcart, LTC Jerry Ladue, MAJ Thomas Knutilla, and MAJ Janet Gohman-Simpson.

Most especially, we are indebted to the efforts of COL Diane Green, now deceased, who continuously maintained visibility over our

research efforts while serving in a variety of U.S. Army Reserve (USAR) senior staff offices and as an Arroyo Center Army Fellow. As a truly professional and insightful soldier, she understood the necessity to change the nature of Army training and provided the connectivity and continuity for our training research activities across several USAR commands. She is greatly missed, but her spirit will continue to be an inspiration for our future endeavors.

ACRONYMS

APOD	Aerial port of debarkation
BPR	Business process reengineering
COA	Course of action
CSS	Combat Service Support
DISCOMs	Division Support Commands
DMC	Distribution Management Center
POL	Petroleum, Oil, and Lubricants
SPOD	Sea port of debarkation
TSC	Theater Support Command

Chapter One

INTRODUCTION

BACKGROUND

As the U.S. Army evolves into a "force-projection Army," the requirement to deploy quickly and conduct missions away from its garrison locations places increasing importance on effective logistics design and management skills. Such skills not only will have to be executed effectively on short notice, they also will have to be applied in increasingly information-intensive and geographically distributed environments, similar in many ways to the environments faced by commercial logistics organizations. But military organizations face special challenges in training logistics managers that do not appear in most corporate training arenas. Military logisticians must be prepared to design, build, and operate distribution systems that provide comprehensive support to hundreds of thousands of deployed people and their equipment. There are a number of challenges:

- These distribution systems do not exist most of the time because large-scale deployments are infrequent, so opportunities for effective on-the-job training are limited.
- Personnel who work in U.S. Army logistics management organizations are largely Army Reserve soldiers who get very little training time focused on their logistics management skills (Bondanella et al., 1997).
- There is a high personnel turnover or "churn" in Army Reserve organizations (Bondanella et al., 1997), so training newcomers is an ongoing task.

- The home locations of reservists in these organizations can be geographically distributed over hundreds of miles. Hence, training regularly with teammates or sister organizations is difficult.

These challenges are made more difficult by the ongoing evolution of Army doctrine covering how these logistics organizations are designed and staffed, the technologies they will use, and their business practices. Two important goals of these new practices are (1) more effective distribution processes and (2) efficiently measured end-to-end—or systemic—performance. This "process perspective" reflects a major change in orientation for an organization that has traditionally stressed a more functionally driven, project-oriented approach, where performance is measured based on how well specific subsegments of the process perform. The Army is trying to follow the lead of prominent private-sector logistics organizations by shifting its focus to activity or process measures and systemic performance.

A DIFFERENT APPROACH TO LOGISTICS MANAGEMENT TRAINING

Using Microworlds for Training

One training tool that has gained prominence with increasing emphasis on systemic performance is the microworld model. Lawler (1987) describes a microworld as a virtual, interactive subset of the world, limited to a specific domain. Microworlds offer interesting environments that learners can explore interactively. The purpose of such environments is to teach understanding of content, such as how gravity works (Smith, 1986), as well as to teach "habits of exploration from their personal lives to the formal domain of scientific theory construction" (Papert, 1980). The theoretical educational strength underlying the use of microworlds is that exploration-based learning is highly efficacious. According to this view, an individual who sets learning goals and then learns by exploring and experimenting, or "learning by doing," richly elaborates and integrates new knowledge into current knowledge.

The term "microworld" appears to have originated at the MIT Artificial Intelligence Laboratory in the early 1970s (Lawler, 1987) and was later popularized by Seymour Papert (1980). Although a microworld

can be built using any enabler, Papert used the term in the context of a "computer-based learning environment for children, in which they could program the environment, see how it responded, and draw out their own understanding of the principles of mathematical relationships."[1] Accordingly, Papert developed the simple but powerful Logo computer programming language, which emphasizes graphics and was used during the early stages of developing computer-based microworlds.[2] Another software application—STELLA—has been used in educational contexts since the early 1980s to support exploratory learning and teach systems thinking. STELLA is a commercial programming language oriented on educational issues in the natural and social sciences and the humanities; its structure parallels ithink, a software product oriented on business issues.[3] A STELLA model begins with the computer visualization and building of a stock-and-flow diagram, which is then supported by underlying mathematical algorithms.[4] Work by Mandinach and her colleagues (Mandinach, 1989; Mandinach and Cline, 1994) has demonstrated how to integrate this category of modeling and simulations into classroom learning.

Others have built and experimented with microworlds (Shute and Glaser, 1990; Shute, Glaser, and Raghavan, 1988; Smith, 1986) and generally demonstrated their qualitative and, in some cases, quantitative efficacy for teaching complex skills. Certainly, inquiry-based learning and the learning tools to support it are not new topics. Cuban (1986) and Cohen (1988), among others, have chronicled several cycles of interest in inquiry learning among academics and educators. Others, like Starr (1994), eloquently point out the poten-

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[1]Peter M. Senge, Art Kleiner, Charlotte Roberts, Richard B. Ross, and Bryan J. Smith, *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization,* New York: Doubleday, 1994, p. 531.

[2]According to an entry for Logo at *www.techweb.com/encyclopedia/*, "Stemming from a National Science Foundation project, Logo was created by Seymour Papert in the mid 1960s along with colleagues at MIT and members of Bolt Beranek & Newman. Originally developed on large computers, it has been adapted to most personal computers."

[3]These software modeling programs were developed by High Performance Systems, Inc., and are described on their Web site, *www.hps-inc.com/customer_center/kb/webhelp/hpsn.htm.*

[4]According to *www.ncsa.uiuc.edu/edu/RSE/RSEindigo/stella.html,* "STELLA II® is the acronym for Systems Thinking in an Experimental Learning Lab with Animation."

tial mislearning and pitfalls of using microworlds to teach complex knowledge, especially with models that cannot be inspected by the learner.

Earlier work at RAND applied microworlds to teach complex academic topics (McArthur and Lewis, 1991; McArthur, Lewis, and Bishay; 1995, and McArthur and Lewis, 1998). The work of Senge et al. (1994) in applying microworlds as "management flight simulators" was a logical extension of discovery learning supported by computer simulations to teach business skills and understanding. Beyond that, it appeared to us that connecting microworlds in a network and allowing multiple learners to collaborate at a distance could address some of the training challenges outlined above. Based on the background just described, we hypothesized that using microworlds to teach Army logistics management skills could potentially provide the following:

- A dynamic simulated theater-level distribution system with which to engage in exploratory learning and to replicate some of the benefits of on-the-job training.
- Focused individual training directly relevant to the skills that Army Reserve soldiers will need if they deploy to support a contingency.
- Readily accessible training to the many new members of the unit without waiting for an annual training exercise.
- Small-group and interorganizational training at a distance: Teams can interact with shared, Web-based microworlds from their home sites or interact with other organizations using shared microworlds.
- Simulations that are less expensive to develop and use for training than the current large, mainframe-based systems that require support staffs.

Few Empirical Data Are Available

Although the potential benefits of using microworlds to train Army logistics managers sound appealing, there is little empirical data on

the effectiveness of microworlds to teach complex management skills and understanding.

Empirically demonstrating the educational effectiveness of microworlds in academic settings is difficult. Empiricists argue that understanding and skills are acquired from exploration with microworlds but that such learning is difficult to test explicitly, and it is similarly difficult to tease out the effect of the microworld from other aspects of the new training materials. Microworlds are not meant to be used in a vacuum, so other pieces of the curriculum to support the guided microworld explorations are also novel to the experimental condition.

Trying to teach management skills to adults using microworlds appears to be empirically documented even less well. Although the importance of microworlds for teaching critical thinking skills to youth and adult learners is argued by consulting companies and providers of simulation tools (e.g., Richmond, 1993), there appears to be little hard data to support their efficacy or their current level of use in firms. Nonetheless, an article by Gross (1996) included a projection done by the Gartner Group, Inc., based on a survey of organizations using business process reengineering (BPR) tools. The article reported that one in four of such companies are using or planning to use products with advanced simulation or animation capabilities and that, according to the Gartner Group report, by 1998 over half of all BPR projects would use some form of simulation or animation.

More recently, Salopek (1998) reported that 60 percent of corporations surveyed used some kind of simulation-based training, but again, effectiveness data were not available. Searches of the Internet provide a number of simulation and consulting service provider sites that list examples of the simulations they have built for clients. Glowing accounts of client satisfaction, but no published outcome studies, can be found.

FOCUS OF THE STUDY

In sum, there is growing interest in the use of microworlds for training complex management skills but few reliable studies assessing their effects. The goal of our study was to provide some quasi-experimental empirical evidence that would aid Army logisticians in eval-

uating the usefulness of microworlds to teach complex logistics management skills, while perhaps informing the debate over the effectiveness of microworlds as training tools. However, we made no comparison between microworld-based training and other training methods on either a cost or effectiveness basis. This is largely due to the fact that there are no other current curricula to teach the content for comparison. These are new concepts to the Army logistics community, so there is no natural set of materials and methods to use for an alternative training condition.

Our study was conducted as part of an effort to design new training for an emerging organization in the Army—the Theater Support Command (TSC)—of which a subordinate organization, the Distribution Management Center (DMC), is responsible for managing the flow of people and materiel throughout the theater of operations. Although learners would ideally spend weeks manipulating a microworld model to test hypotheses and gain system understanding, we were severely constrained in terms of the time available. We had only a three-hour window in which to conduct the evaluation study. We therefore designed a three-hour training curriculum around a microworld model that represents a simplified version of the distribution management process. During the training session, the model was run on a large projection screen. Participants were given many opportunities to discuss hypotheses about the system, but due to the time constraint, it was not feasible for them to manipulate the model on an individual basis. The main goal of the session was to teach the learners about the consequences of their decisions over time and across the entire system. In reaching this goal, it was necessary to also provide soldiers with some background knowledge and basic skills relevant to performing as part of a TSC.

ORGANIZATION OF THE DOCUMENT

The remainder of this report describes our microworld-based training evaluation study with U.S. Army Reserve soldiers learning logistics management skills. We then present the results of that study and close with a discussion of how we believe our models and curriculum can be broadened and improved to provide better learning support for locally gathered and distributed teams.

Chapter Two

METHOD

PARTICIPANTS

Sixty-five Army reservists from theater-level distribution management organizations participated as part of a two-week annual training event. Table 1 is a display of some of the important demographic characteristics of the participants.

MATERIALS AND APPARATUS

All participants were given a "Battle Book" at the start of training; it contained a sheet explaining participants' rights as human subjects in an experiment, assessment forms, and paper copies of the training slides.

A dynamic microworld model was also used during training. The microworld model operates as a computer simulation superimposed on a map that represents the distribution of supplies on the Japanese island of Hokkaido. During training, the simulation allows the user to monitor the performance of the distribution network over a period of 24 days by way of animation and numerical displays. This occurs over 92 time steps in the model so that a single time step represents a six-hour period. The model allows users to control the distribution policy throughout the network and to evaluate its long-term effects. Variables that the user can modify are collected in a notebook that is accessible from a pull-down display.

Figure 1 shows the model as it appears to the user for supply distribution on Hokkaido. On the map, each area of interest is a node, bearing the name of the principal city or camp (e.g., Nishiokoppe).

Table 1

Demographics of the Participants

Demographic Variable	Number of Participants
Enlisted/officer	
Total enlisted (E5–E9)	17 (90% E7–E9)
Total officer (O2–O6)	47 (80% O4–O5)
Civilian	1
Time in permanent unit	
One year or less	20
Between 1 and 3 years	17
Over 3 years	28
Time in current job position	
One year or less	35
Between 1 and 2 years	14
Over 2 years	16
Time in active duty logistics unit	
Never	36
Three years or less	12
Between 3 and 10 years	9
Over 10 years	8
Degree of civilian education	
High school diploma	5
Associate degree	8
Baccalaureate degree	25
Master's degree	17
Other graduate/professional degree	10

Each node also has a number used to designate it in the notebook. Within each node is a vertical bar that serves as a graphical display of the supply level at the node. Next to the bar is a number that provides the same information. If the level of supplies exceeds set limits, a red square above the bar lights up.

Supplies originate in CONUS and in Japan and travel by ship to the sea port of debarkation (SPOD) at Atsukeshi, the SPOD at Kushiro, or the aerial port of debarkation (APOD) at Kushiro. Supplies then travel either over land or by air. Over land, they are taken to Teshi-

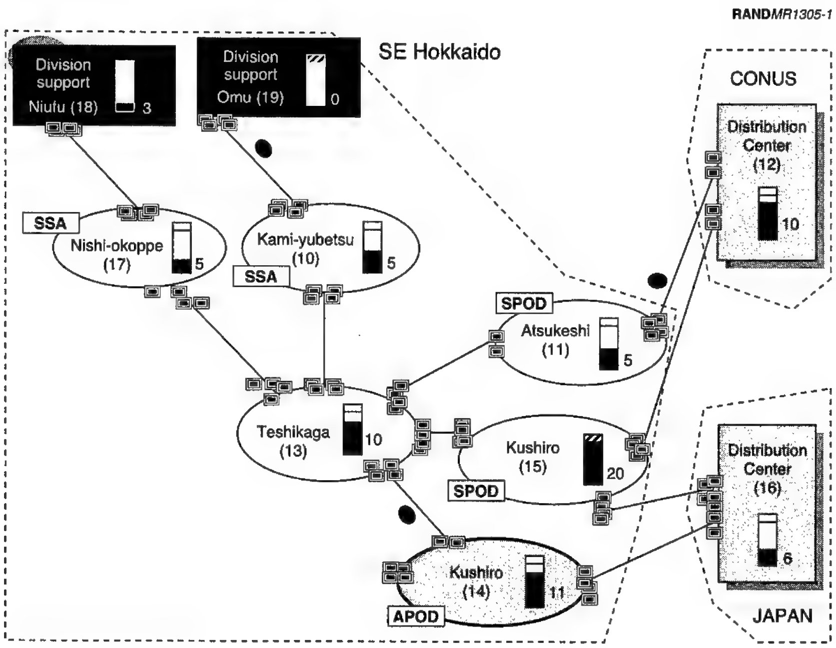

Figure 1—Microworld Model

kaga. By air, they are taken directly to Niufu from the APOD at Kushiro. At Teshikaga, some supplies are routed to Kamiyubetsu and others to Nishiokoppe. Kamiyubetsu and Nishiokoppe feed their supplies to Omu and Niufu, respectively.

Supplies are carried between nodes by transportation resources rather than by individual vehicles. A transportation resource is an aggregate of vehicles and may correspond to a train, a convoy of trucks, or a number of transport aircraft or ships. When the model operates, a transportation resource appears as a colored circle that moves along the transportation corridors that connect nodes. If the transportation resource is loaded, the pattern in the circle is solid. If the resource is empty, the pattern in the circle is hatched. Each transportation resource is uniquely labeled by color so that the user may keep track of its position and status.

DESIGN AND PROCEDURE

Two identical demonstration training sessions were conducted, one in the morning and one in the afternoon. Thirty-one people participated in the morning session, and 34 participated in the afternoon. A single session, including both training and assessment, was designed to be completed in three hours. Shortly before the start of the session, all participants were asked to provide demographic information about themselves, including their ranks, levels of civilian and military education, and participation in related pilot studies. After completing the demographics form, they were asked to close their Battle Books and wait for the training session to begin.

Participants in the training session were randomly assigned to one of two groups: Full Assessment and Posttest Control. For participants in the Full Assessment group, the session began with the administration of a pretest to measure the initial level of participants' skills. The pretest was followed by training and then by a posttest. The Posttest Control group received identical training but completed only the posttest. The purpose of the control condition was to determine whether experience with the pretest would itself affect performance on the posttest. Few participants were needed to test such an effect; thus, there were 52 participants in the Full Assessment group and only eight in the Posttest Control group. The remaining five participants took the pretest only and were excluded from the analysis. Following the description below of the training session, we discuss the details of the assessment strategy.

Training

The training session focused on distribution management skills. We identified and trained participants on three broad categories of skills that are considered by subject matter experts to be central to performance as part of a TSC: (a) basic system knowledge and skills, (b) measurement and trend identification skills, and (c) course-of-action analysis skills. We used a mix of methods to teach these skill sets, and the complexity of the methods was commensurate with the complexity of the skill.

In teaching basic system knowledge, we relied almost exclusively on lectures. Here, we presented a short lecture (10 minutes) on the

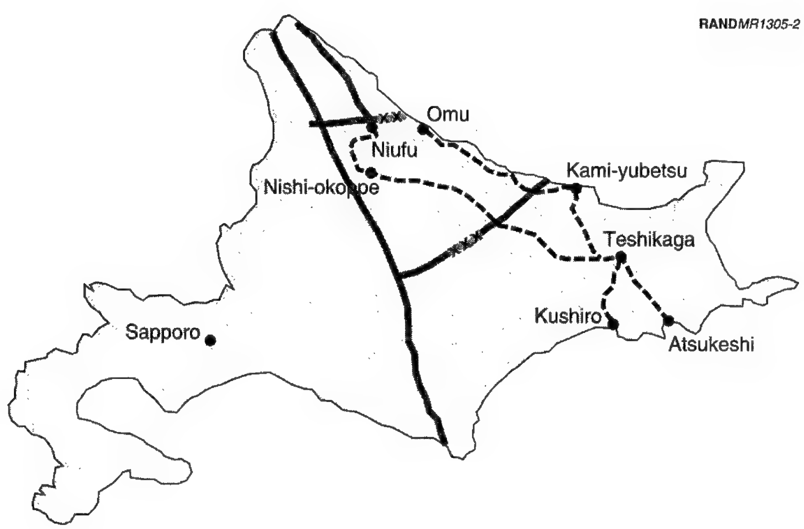

Figure 2—Force Dispositions on Hokkaido

missions and organization of the TSC and DMC. Discussion during this phase was minimal.

The second section of the training session was a 15-minute group discussion of metrics and measurement. At the start of this section, we presented a hypothetical scenario and distribution network on the island of Hokkaido (depicted in Figure 2). The scenario was a hypothetical joint bilateral operation between the Americans and the Japanese, with the American forces on the east side of the island, facing north, and the Japanese Defense Forces on the west side. The objective was to push the "Orange Forces" (the enemy) out of the northern part of the island, and the logistician's job was to manage the flow of a general class of supply from the ports to the Division Support Commands (DISCOMs)—the retail organizations that supply the tactical units. The group discussion of measurement was structured around several issues, including identification of the customer(s), selecting appropriate metrics, and thinking about different time horizons.

The final and longest training segment focused on the analysis of a distribution network. In this segment, as we began to train the more

complex skill of managing a dynamic system, we emphasized the use of microworld simulations. The simulations were deliberately simplified to teach a few, very specific concepts and skills, including how to recognize and characterize patterns in data and how to approach the analysis of different courses of action.

At the start of this final section, we reintroduced the scenario and operations area (Figure 2). We then presented a schematic of the general supply distribution network on the same map (Figure 3). Next we introduced our highly simplified microworld model of supply distribution and explained to participants the mechanics, graphics, and animation of the model.

After a 15-minute break, the first dynamic network was presented. It was a hub-and-spoke system with the hub at a tank farm between points of debarkation and DISCOMs (Figure 4). After describing the network in detail, we asked participants as a group to generate predictions as to the performance of the system and to explain the

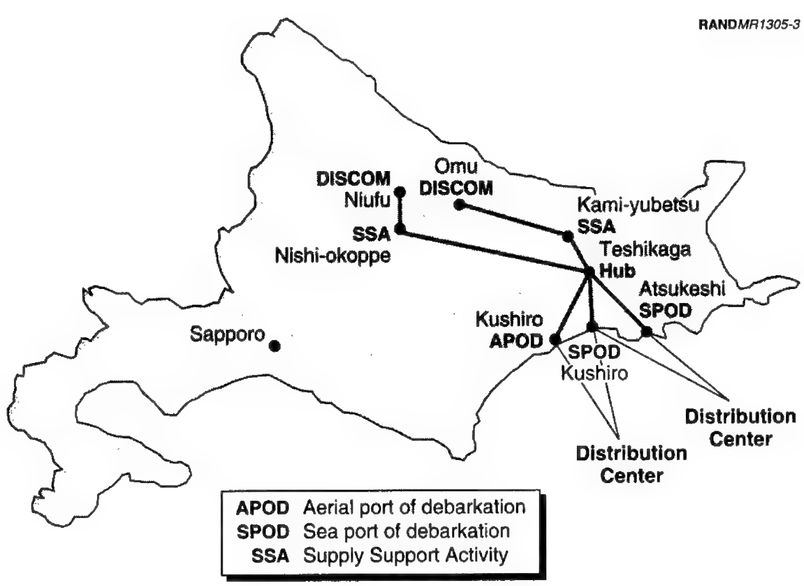

Figure 3—Distribution Network

rationale for their responses. Following the prediction exercise, we ran a microworld simulation of the hub-and-spoke system that enabled participants to see the effects of a pure hub-and-spoke policy over time. The outcomes they predicted and subsequently witnessed included a bottleneck at the hub and unacceptably low supply levels at the DISCOMs ("starving customers").

Before running our simulation of a pure direct-delivery system from the ports to the DISCOMs, we showed participants a representative diagram (depicted in Figure 5) and asked not only for their predictions, but also for comparisons to the performance of the hub-and-spoke system. We then moved to a discussion about important factors to consider in evaluating a course of action (COA), e.g., hub-and-spoke or direct delivery.

Following the prediction exercise, participants watched a simulation run of the direct-delivery system and noted both positive and negative aspects of a switch to direct delivery. The DISCOMs received

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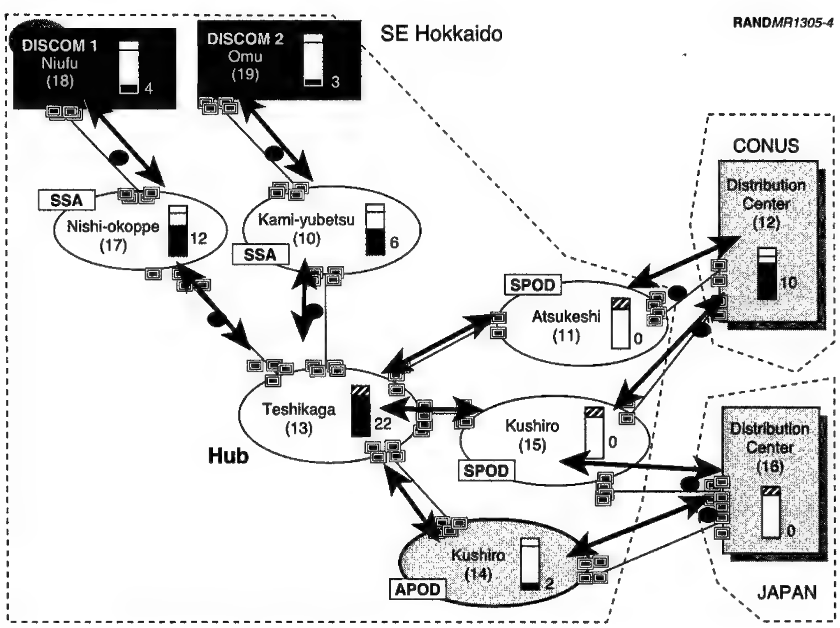

Figure 4—Microworld Model of Hub-and-Spoke Scenario

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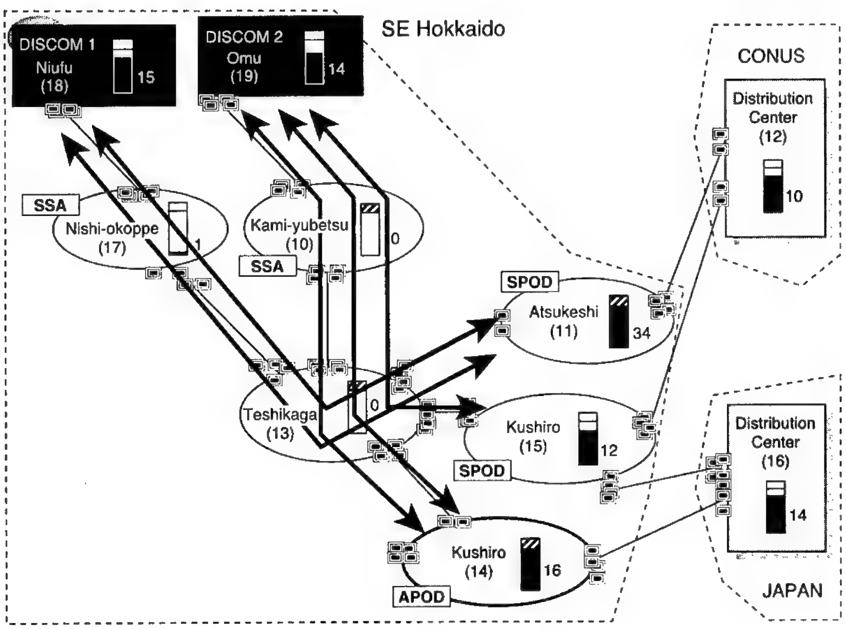

Figure 5—Microworld Model of Direct-Delivery Scenario

supplies in a more timely manner, but intermediate nodes were starved, and long transit times led to backups at the ports. Following this final run, we displayed graphs of the supply levels of several nodes over time, reviewed factors to consider in evaluating COAs, administered a 25-minute posttest, and then presented a more complex model with a built-in feedback loop. The final feedback model was included only as a demonstration of model capabilities and was not a target of the assessments. Feedback from participants was collected in the final five minutes of the session.

Assessments

For the Full Assessment group, two sets of assessments—a pretest and a posttest—were embedded in the three-hour session. The tests were administered immediately before and after training, and participants were given 30 minutes to complete each set.

Both subjective and objective measures of performance were collected during each test. The subjective measures consisted of participant ratings of their own understanding of concepts spanning all three categories of skills: basic system knowledge, trend identification, and COA analysis. Less than five minutes was required to complete the subjective questions.

We collected objective measures of skill for only the two most complex categories: trend identification and COA analysis. Basic system knowledge was not tested, because it consisted mainly of information that could be referenced and did not require problem-solving skill. Participants were given ten minutes to answer questions pertaining to each of the two skill categories—20 minutes for the two combined. Free-response feedback was also collected and, along with administrative time, accounted for the remainder of the 30-minute time blocks.

For the objective test questions, participants were given a specific scenario (e.g., Figure 6), a map of the system to analyze (Figure 7), and a table of data indicating levels of POL (petroleum, oil, and lubricants) or numbers of personnel at each location in the network over a period of ten days (Figure 8). We asked participants to answer two main questions based on the information provided. Question 1 asked participants to identify problematic patterns in the data, and Question 2 involved COA analysis (see Figure 9).

The initial test scenario described a poorly functioning hub-and-spoke system, although it was left to participants to recognize that it was not performing well. In devising the test materials, we built several problematic trends or patterns into the data, some more subtle than others, and asked participants to identify them (Question 1). Before presenting the question on COA analysis, we added a short continuation to the scenario indicating that the commander was unhappy with the hub-and-spoke system and was considering a switch to direct delivery. Participants were asked to list the factors they would consider in deciding whether to switch to a direct-delivery system (Question 2).

The 2nd COSCOM commander is using an intermediate petroleum tank farm located at Bihiro, containing approximately 3.2 million gallons of JP8 fuel, to support both the combat and combat support elements within the boundaries of 2nd Corps. Army-owned line-haul fuel tankers provide resupply to the farm from head terminals located at Shibetsu and Shiranuka. Once the fuel arrives at the tank farm, petroleum handlers download it into bags and later issue it to 5,000-gallon fuel tankers for delivery to corps-level fuel system supply points (FSSPs). Once there, the fuel is stored in the FSSPs until it is delivered to divisional forces by divisional fuel tankers.

Figure 6—POL Scenario Used in Testing

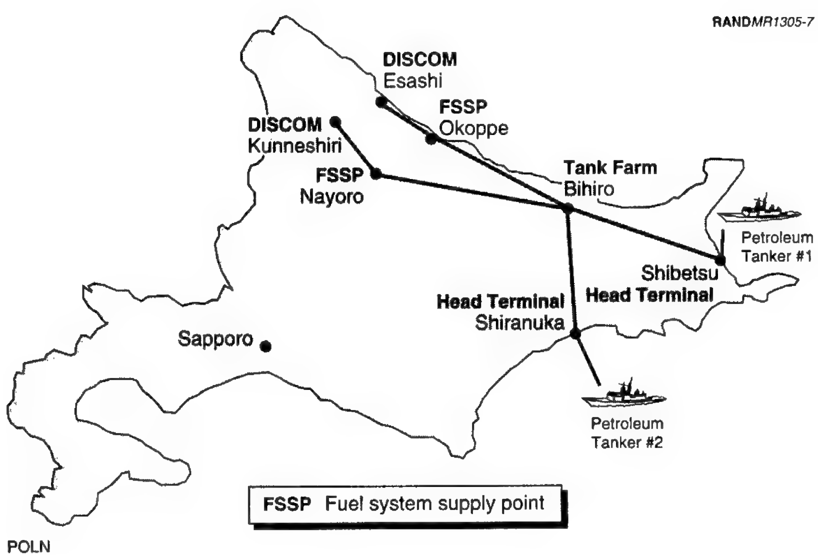

Figure 7—Map of POL System

Supply levels (in thousands of gallons)

	OPDS Shiranuka	OPDS Shibetsu	Tank Farm Bihiro	FSSP Nayoro	FSSP Okoppe	DISCOM Kunneshiri	DISCOM Esashi
Targets:	6,000	6,000	3,200	60	60	30	30
Day 1	1,000	1,000	0	0	0	0	0
Day 2	1,500	1,500	1,000	30	30	0	20
Day 3	2,000	2,500	1,500	15	20	5	10
Day 4	3,500	3,000	2,000	20	30	10	5
Day 5	3,000	4,000	1,500	10	20	5	25
Day 6	5,000	3,500	3,000	25	15	10	15
Day 7	6,500	5,000	3,500	35	10	5	10
Day 8	6,000	6,000	4,000	45	30	10	7
Day 9	6,800	5,000	4,500	60	20	10	20
Day 10	4,000	4,000	4,000	60	15	5	15

Figure 8—Data for POL Scenario

Question 1: Trend Identification

What trends or problematic patterns do you detect currently or see developing in this POL network, and where specifically do they occur?

Question 2: COA Analysis

The COSCOM commander is concerned about the low fuel supply to divisional forces at Kunneshiri. He is therefore considering switching to a system of direct delivery from the head terminal at Shiranuka to the DISCOM at Kunneshiri. He asks for your input. List the factors you would consider in deciding whether to switch to the new system.

Figure 9—Sample Assessment Questions

We also included a simple question testing a participant's proficiency in reading data from tables of numbers (Question 3) to ensure that performance on the questions of interest did not reflect the absence of this prerequisite skill. Data from participants who failed to answer the question correctly were analyzed separately.

Each participant was randomly assigned to a single test vignette, either POL or personnel. The POL distribution vignette focused on the distribution of fuel between different locations in the network. The personnel replacement vignette described the flow of personnel between locations. Half of the participants were exposed to the POL vignette and half to the personnel vignette. Each vignette had two forms, one for the pretest and one for the posttest. Each participant in the Full Assessment group completed both forms of a single vignette. All vignettes were located on the east side of the island of Hokkaido, thereby keeping the geography constant for the pretest, training, and posttest. However, different city names were used for each of the two test forms and for the curriculum as follows: Test Form A for POL and Test Form A for personnel made use of identical maps, and the numbers in the two data tables differed only by a constant. The same was true of Test Form B for POL and Test Form B for personnel. Further, Test Forms A and B for both vignettes featured identical underlying network structures. This way, the vignettes differed only in terms of cities used, the items being moved (POL or people), and the corresponding magnitude of the numbers. They did not differ in context or structure. The order of the test forms was counterbalanced within vignettes, and the maps for all the test forms differed (in terms of city names and locations) from the map used during training.

Like participants in the Full Assessment group, half of the participants in the Posttest Control group were tested with the POL vignettes, and the other half with the personnel vignettes. Posttest forms were also counterbalanced across groups of participants in the Posttest Control group. During administration of the pretest to the Full Assessment group, the Posttest Control group was escorted to a separate room for casual discussion, unrelated to the training topics.

Scoring

A number of steps were required for the scoring and analysis of the responses to the objective questions. The scoring schemes for Questions 1 and 2 are presented in detail in Tables 2 and 3, respectively. As mentioned above, for Question 1, participants were given a scenario, map, and table of data, and were asked to identify trends in either the POL distribution or personnel replacement system. They were scored on their success in finding five "problematic trends" in the data table. One point was assigned for each trend correctly identified, yielding a total possible score of 5.

The scoring of the COA analysis question (Question 2) was more complex. For this question, participants referred to the original scenario, the original map, and an alternative (direct-delivery) scenario. They were asked to list the factors they would consider in evaluating a potential switch from the hub-and-spoke system to a pure direct-delivery system.

Before delivering the training, we split the potential set of responses to Question 2 into the ten categories listed in Table 3. Participants were given a maximum of one point per category, regardless of the number of responses they provided for that category. So, for example, five responses addressing the availability of resources would yield only one point.

Three raters scored the tests. First, 20 tests were scored by the three raters as a group to help ensure that all raters agreed on the application of the scoring scheme. The remaining tests were split into three groups, and each group of tests was assigned to two of the three raters. Thus, each rater scored two-thirds of the tests after the group-scoring phase.

After the scoring was completed, a factor analysis was conducted on the ten categories of responses to Question 2 to determine whether they could be split into meaningful subgroups. As a result of the factor analysis, the responses were grouped into three separate measures: (2a) identifying impacts of trends in data, (2b) coordinating and influencing, and (2c) tactics and resources. The responses in the final category—tactics and resources—were included after pilot data

Table 2

Question 1: Identifying Trends in Data

Number of Points	Trend	Example (from POL Vignette)
1	Bottleneck at the hub	Buildup of supply at Akan
1	Underutilized node	Kitami is consistently underutilized
1	Starving customers	Supply level at Niufu DISCOM is low
1	Fluctuating around maximum	Port Urohoro around maximum
1	Growing to maximum	Kamikawa FSSP reaching capacity
Maximum: 5		

Table 3

Question 2: Analyzing Courses of Action

Number of Points	Response Group	Response Category: Does the Policy . . .
2a	Identifying impacts of trends	
1		Alleviate the current problem?
1		Have impacts on customer?
1		Have impacts on sources of supply or intermediate supply points?
1		Have different short-term and long-term impacts?
Maximum: 4		
2b	Coordinating and influencing	
1		Integrate with policies of other support system components (e.g., HNS, bilateral ally, etc.)?
1		Exercise influence on higher and/or lower echelons?
1		Agree with overall mission?
1		Introduce tradeoffs when compared to alternatives?
Maximum: 4		
2c	Tactics and resources	
1		Have tactical implications?
1		Have impacts on resources in theater?
Maximum: 2		

were collected in an effort to acknowledge the importance of traditional Army concerns; however, the category was not an explicit part of our training goals for this demonstration session.

One can think of the various dependent measures on a continuum of complexity. Question 1 tests the simplest skill: identifying trends in data. Question 2a, identifying impacts of trends, builds on the first skill to begin quantitatively-based analyses of courses of action. That is, a logistician must first be able to make sense of data before moving on to the implications of those data. Finally, once the impacts of trends are determined, the logistician can consider influencing and coordinating with other support system components (Question 2b) to achieve a desired course of action.

The demonstration session and the microworld model used in the session were aimed most strongly at the first two skills. The third skill—coordinating and influencing—was mentioned, but was not emphasized.

Chapter Three

RESULTS

The learners' performance on the objective questions as well as their subjective ratings of their own understanding suggest that participants acquired a significant amount of knowledge and skill in distribution management as a result of participating in the training session.

OBJECTIVE MEASURES

Before proceeding with analyses of participants' performance on the objective questions, we calculated inter-rater reliabilities. The mean correlation between pairs of raters' scores was 0.80, leaving us reasonably confident that the three raters applied the scoring scheme equivalently. In all further analyses of objective test data, we used the average of the scores assigned by the two raters for each test.

Only two participants failed to answer Question 3 (our manipulation check testing participants' ability to read the data tables) correctly on the pretest, and both participants answered a similar question correctly on the posttest. This suggests that they acquired this basic skill during the training session, and their data were therefore combined with the rest of the sample.

Participants showed significant learning of the two skills emphasized in the demonstration session (see Figure 10). On average, learners were able to identify one more trend out of a possible total of five after participating in the session (Question 1: $\Delta = 0.91$, $t(51) = 5.93$, $p < .0005$). Gains on the second skill—identifying impacts of trends—were smaller, but still reliable (Question 2a: $\Delta = 0.47$, $t(51) = 4.00$, $p < .0005$).

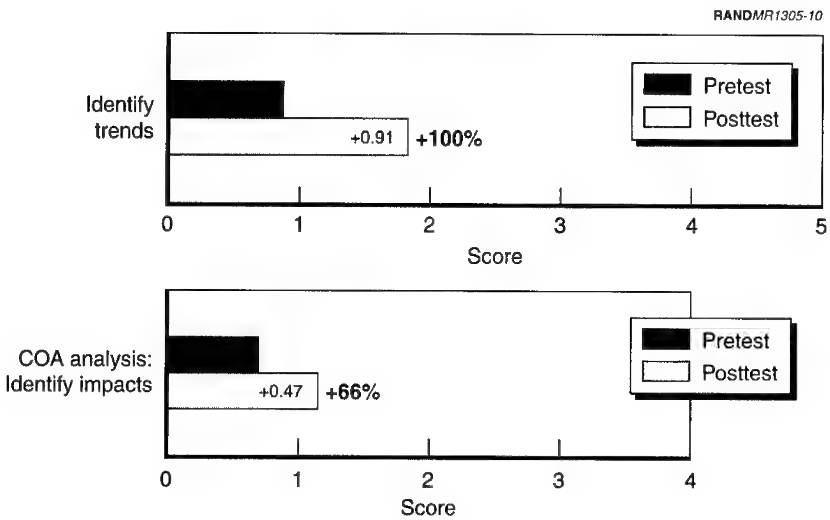

Figure 10—Performance of the Full Assessment Group on Question 1 (Identifying Trends) and Question 2a (Identifying Impacts of Courses of Action)

Skills that were not the explicit targets of the training curriculum (i.e., coordinating and influencing, and tactics and resources) did not improve significantly (Question 2b: $\Delta = 0.10$, $t(51) = 0.90$, $p > .05$; Question 2c: $\Delta = -0.04$, $t(51) = -0.68$, $p > .05$). The mean posttest scores for all four measures fell in the low to middle part of the range for each measure and were as follows: M(Q1 posttest) = 1.84, M(Q2a posttest) = 1.17, M(Q2b posttest) = 0.73, and M(Q2c posttest) = 0.75.

Based on the results of the *t*-tests, we restricted all further analysis to Questions 1 and 2a. Both in identifying trends and identifying impacts of trends, participants showed larger gains for the POL vignette than for the personnel vignette; however, the differences between vignettes failed to reach significance. For Question 1, the mean improvements on the POL and personnel vignettes were 1.13 and 0.69, respectively ($t(50) = 1.45$, $p > .05$). The mean posttest-pretest difference scores for Question 2a were 0.58 for POL and 0.36 for personnel ($t(50) = 0.93$, $p > .05$). It is worth noting that the POL vignette is arguably a closer analog to the general supply vignette used during the training session than is the personnel vignette. Thus

there may have been more effective transfer of learning to the POL vignette, explaining the consistent, albeit nonsignificant, difference between the means for the two test vignettes.

After conducting the preliminary *t*-tests reported above, we produced a correlation matrix to identify the variables that were related to our two main outcome measures. The following variables were included in the correlation matrix: (1) outcome measures—pretest and posttest scores for each of the objective questions, posttest-pretest difference scores; (2) experimental control variables—vignette (POL or personnel), test form (A or B), and test order (AB or BA); and (3) demographic variables—rank, time served in permanent unit, time served in current position, degree of civilian education, enlisted versus officer, and prior training (i.e., participation in related pilot studies).

None of the variables correlated even moderately with the posttest-pretest difference scores; however, a few demographic variables looked as though they varied with either pretest performance, posttest performance, or both. We included those variables—civilian education, enlisted/officer, and prior training—in a regression model. The results of the regressions are presented in Tables 4 and 5.

The level of civilian education had no significant effect on either pretest or posttest performance for either measure. However, as shown in Figure 11, both on the pretest and on the posttest, officers were better at identifying trends in data than were enlisted participants [*M*(officer, pretest) = 1.18, *M*(enlisted, pretest) = 0.30, *M*(officer, posttest) = 2.16, *M*(enlisted, posttest) = 1.03]. The two groups showed statistically equivalent gains from pretest to posttest. A similar pattern was seen for Question 2a [*M*(officer, pretest) = 0.93, *M*(enlisted, pretest) = 0.16, *M*(officer, posttest) = 1.37, *M*(enlisted, posttest) = 0.69]; however, the effect was not statistically significant for the posttest.

Eight learners had previously participated in RAND pilot studies on topics similar to those presented during the demonstration training session. Although there was evidence that participants with prior training experience knew more at the start of the session and also at the end of the session, they did not make bigger gains in performance than did other participants. On Question 1, participants with

Table 4

Summary of Regression Analysis for Variables Predicting Pretest Performance ($N = 52$)

	Q1: Identifying Trends		Q2a: Identifying Impacts	
Variable	B	SE(B)	B	SE(B)
Test vignette	0.02	0.23	–0.18	0.19
Civilian education	0.04	0.13	–0.02	0.10
Enlisted/officer	–0.66	0.30*	–0.65	0.24*
Prior RAND training	0.64	0.31*	0.59	0.26*

*$p < .05$.

Table 5

Summary of Regression Analysis for Variables Predicting Posttest Performance ($N = 52$)

	Q1: Identifying Trends		Q2a: Identifying Impacts	
Variable	B	SE(B)	B	SE(B)
Test vignette	0.46	0.36	0.05	0.26
Civilian education	0.13	0.20	0.09	0.14
Enlisted/officer	–0.82	0.47*	–0.27	0.34
Prior RAND training	0.65	0.50	1.09	0.35*

*$p < .05$.

prior training scored higher on both the pretest and the posttest than other participants did [*M*(prior training, pretest) = 1.69, *M*(no prior training, pretest) = 0.78, *M*(prior training, posttest) = 2.63, *M*(no prior training, posttest) = 1.69], but the difference between the two groups was significant only for the pretest. As shown in Figure 12, participants with prior RAND training experience were significantly better at identifying impacts of courses of action, both on the pretest and on the posttest, than were those without prior training [*M*(prior training, pretest) = 1.42, *M*(no prior training, pretest) = 0.58, *M*(prior training, posttest) = 2.25, *M*(no prior training, posttest) = 0.98].

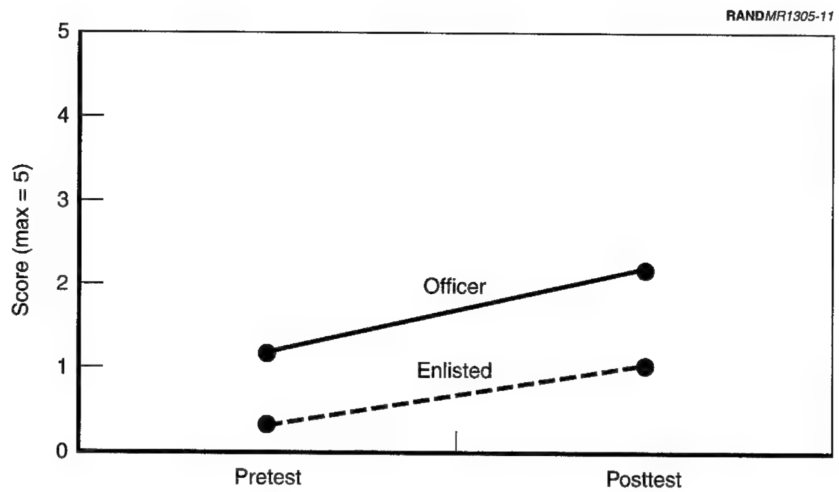

Figure 11—Performance of Officers and Enlisted Soldiers on Question 1 (Identifying Trends)

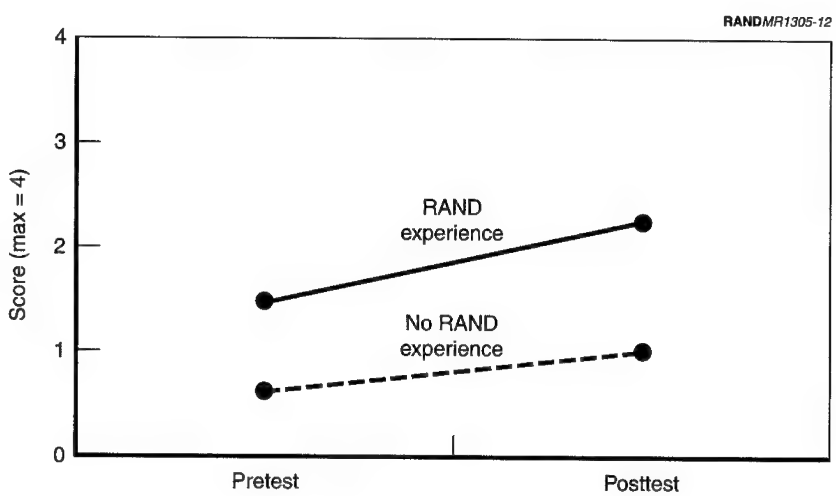

Figure 12—Performance of Participants With and Without Prior RAND Training on Question 2a (Identifying Impacts of Courses of Action)

Posttest data from the Posttest Control group were compared with data from the Full Assessment group to determine whether experience with the pretest itself had any effect on subsequent posttest performance (see Figure 13). There was no evidence of an effect of pretest experience on the posttest ($t(50) = 0.46$, $p > .05$ for Question 1; $t(50) = 0.49$, $p > .05$ for Question 2a).

SUBJECTIVE MEASURES

Consistent with the objective measures, participants believed their understanding of key concepts related to distribution management increased during the course of the three-hour training session. As shown in Figure 14, on a scale of 0 to 10, they rated their understanding of key concepts between two or three points higher after training than before training. Specifically, participants reported increases in their understanding of how to measure a theater distribution system ($\Delta = 3.00$, $t(51) = 12.29$, $p < .0005$), how to evaluate alternative distribution policies ($\Delta = 2.88$, $t(51) = 11.46$, $p < .0005$), the impacts of policies over time ($\Delta = 2.21$, $t(51) = 7.51$, $p < .0005$), the impacts of policies on other organizations ($\Delta = 1.97$, $t(51) = 8.18$, $p < .0005$), and how to manage a general supply distribution network ($\Delta = 2.15$, $t(51) = 7.73$, $p < .0005$).

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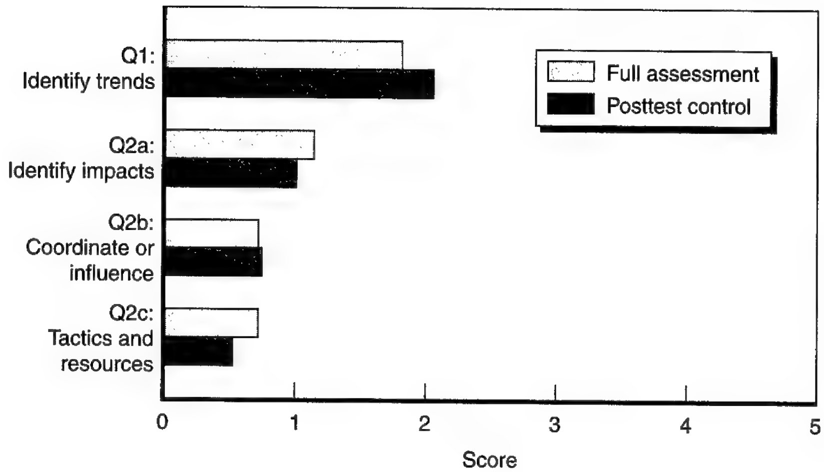

Figure 13—Posttest Performance of the Full Assessment Group and Posttest Control Group on Questions 1, 2a, 2b, and 2c

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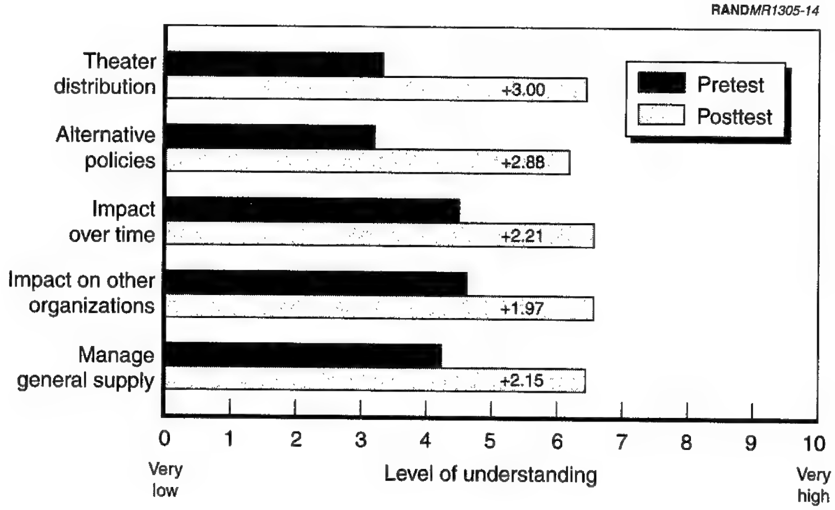

Figure 14—Changes in Participants' Self-Ratings of Understanding of Key Concepts Related to Distribution Management

Chapter Four

DISCUSSION

ALL GROUPS LEARN MANAGEMENT SKILLS UNDER DIFFICULT ASSESSMENT CRITERIA

Foremost among this study's findings are the significant improvements in logistics managers' ability to identify trends in data and interpret the effects of those trends. It should again be emphasized that this study was constructed to provide a challenging environment for learners. The authors did not want to simply "teach to the test." Learners encountered different scenarios for learning and assessment. How the data were formatted also differed from instruction (graphical) to assessment (table of numbers). Earlier research on learning and problem solving in analogical settings (see, e.g., Gick and Holyoak, 1983) has shown that such changes to the contexts in which problems are presented makes transfer from one problem (e.g., the training scenario) to other problems (e.g., the assessment scenarios) particularly challenging.

Also of note is the amount of knowledge we attempted to teach in a very short time. We sought to teach these learners a new way of viewing their organizations and work. Whereas the emphasis in the past has largely been on monitoring and accounting for past events, we emphasized systemic, dynamic, and proactive management. At the same time, we sought to teach very specific skills—finding trends in data and identifying the impacts of those trends. The majority of the discussion and microworld use directed specifically toward our teaching goals amounted to a total of only 60 minutes of actual time on task. The other two hours of the session were devoted to introductions, assessments, a short break, and a later demonstration of a

feedback loop in the microworld shown after the assessment. This is very little time in which to cover the amount of material we sought to teach. We were asking our students to "drink from a fire hose" of training content, and they clearly learned some skills.

Finally, we were quite interested in the fact that all groups of learners improved their skills. Performance increased by about the same amount for both officers and enlisted soldiers, even though officers can generally be presumed to have higher levels of formal education. Trainees with previous training experience in these topics also increased their skill levels, so there is some evidence that this learning is cumulative. Overall, the small but significant learning results justify some optimism regarding such training methods and content. Moreover, we believe actual training would be carried out in ways that would yield much stronger learning results; this is further justification for our optimism.

IMPLEMENTING MICROWORLD-BASED TRAINING UNDER OPTIMAL LEARNING CONDITIONS

It is important to remember that our study was implemented to meet the constraints of quasi-experimental conditions. We wanted all our trainees to see the same materials and be exposed to the same explorations. These constraints run directly counter to some of the basic strengths of exploratory learning via microworlds. Under more ideal conditions, learners interact with the microworlds either individually or in small groups. Hypotheses are generated, predictions are made about system performance under certain conditions (both short- and long-term outcomes as well as side effects), and the simulation is run. The results of the simulation run are compared to the predictions and then conclusions are drawn, new hypotheses are generated, and new explorations are planned. This exploratory cycle can be fast or slow, depending on the results of the explorations and the ensuing discussions.

The conditions of this study included an introduction to the microworlds, including the most basic explanations of the graphics and animation. For example, trainees learned what the transportation assets looked like when they were full versus empty, what the bar graphs denoted, and how to parse the overall flows of resources as

the simulation was run. The costs of time spent learning these basics of how to understand the microworld would be amortized over more sessions in actual training use.

ASSESSMENTS ADDRESS A SUBSET OF TRAINING CONTENT

We sought to assess several aspects of how a complex distribution system is understood and managed. This includes the larger concepts of how to view systems as interrelated, interacting sets of entities that jointly produce a business process. It also includes a "customer" orientation, how to think about end-to-end system performance, and how to design appropriate metrics to assess how the system is performing. As mentioned earlier, these are new concepts to most of the trainees in the context of Army logistics operations.

In conducting the study, we faced serious constraints on the amount of assessment time. We believe that trainees learned more than we had the time to assess. In debriefings and discussions with trainees after our pilot sessions and the study reported here, it appears they acquired a deeper understanding of how to think more systemically and be more proactive in their planning. This differs significantly from the traditional "reactive" management strategies under which they normally train. Comments about trainees learning to lengthen their planning horizons were not uncommon. This result is backed by the trainees' self-reports of their knowledge before and after the study as reported in Chapter Three. Their ratings of their understanding of important topics increased by a minimum of 40 percent and, in one case, nearly 100 percent from pretest to posttest.

FOLLOWING UP WITH DIFFERENT CONTROL CONDITIONS

The simple control condition for this study established that there was no significant learning from taking the pretest: Trainees who did not take the pretest performed no differently than trainees who did. However, there are a number of other appropriate control conditions that could answer questions about how microworld-based training compares to other training methods.

One of the problems in assessing new uses of technology to support learning is that new training methods like microworlds are not implemented in a vacuum. As in this study, the new methods are used because we want to teach new content effectively. Other methods (e.g., discussions) and other pieces of the curriculum are added to support the microworld use. It therefore becomes difficult to isolate the effects of the microworld exposure.

Complicating matters in the context of this study is the fact that there are no other current curricula to teach the content for comparison. These are new concepts to the Army logistics community, so there is no natural set of materials and methods to use as a control condition. This is unfortunate, because a demonstration of the superiority of a curriculum using a microworld model over the equivalent curriculum without such a model would clearly provide the strongest support for the use of microworlds in the training of logistics skills.

Given the availability of alternative curricula, potentially useful control conditions could teach the same content but not use dynamic simulations. They might instead involve the use of pictures of the distribution networks coupled with discussions of the different hub-and-spoke versus direct-delivery scenarios. Another option would be for the Army to design curricula to teach the same content and compare the performance of the two groups on the same pretests and posttests. Care must be taken in such comparisons that the curricula and the instructors are not simply teaching to the test.

FUTURE DIRECTIONS: DISTRIBUTED, COLLABORATIVE MICROWORLD WITH REUSABLE LIBRARIES OF SCENARIOS

If microworld-based curricula continue to demonstrate promise as effective methods for teaching complex logistics management skills, a number of directions could be pursued to support their use. First, reusable libraries of scenarios could be developed and accessed via networks. In fact, this project is already developing microworlds to help teach the skills that we did not cover in depth, namely, how to coordinate with and influence other organizations. We developed a microworld that simulates the process of designing and building the distribution network we used as the focus of our study. Key to this microworld are learning the information and command flows

between organizations and how the actions of different organizations or environmental events can have effects on the design and construction process. This microworld is linked systemically to the activities of the distribution network as it evolves: If the pieces of the deployed distribution network are not completed on time, materiel starts to back up at the ports and becomes vulnerable.

Having networked access to microworld-based curricula (via the World Wide Web, in the most general form) would also allow access to other collaborative problem-solvers from both shared and sister organizations. Tools to support such distributed use of microworlds are already being made available by the developers of tools to build microworlds. This would allow trainees in geographically distributed locations to work together simultaneously.

We believe that there is a great deal of promise for the effectiveness of microworld-based curricula for training complex management skills. The comments and ratings of the trainees who participated in our microworld-based training sessions support our optimism. Over the course of their careers, Army personnel have been exposed to a great deal of training, both good and bad. Hence, they are critical consumers of new training and tend to be very direct about their opinions. Their views of the current and potential usefulness of microworld-based training methods and curricula, as reported in their free responses, were very positive. Part of the post-training assessment asked trainees to rate the effectiveness of the simulations in "developing your understanding" on a number of topics we sought to teach. The ratings were either "not at all useful," "somewhat useful," "useful," or "very useful." Thirty-nine percent of the trainees rated the simulations as "useful" and 44 percent rated them as "very useful."

Microworld-based curricula appear to offer reasonable solutions to the challenges faced by the Army in training logistics managers. They offer dynamic, semirealistic simulated distribution systems to support exploratory learning. They can focus on teaching specific, job-critical skills without waiting for larger-scale training exercises, with either locally gathered or distributed groups of learners. They appear to require fewer resources to build and use than other current, large simulation-based learning tools. If these promises continue to hold true, microworld-based curricula will be strong

candidates for training a wide variety of management skills in both military and commercial settings.

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Exploring the Use of Microworld Models to Train Army Logistics Management Skills

The authors performed a study to assess the effectiveness of using microworlds to train Army logisticians. Sponsored by the U.S. Army Combined Arms Support Command, the study was part of an effort to design new training for an emerging organization in the Army—the Theater Support Command (TSC)—which, among other things, is responsible for managing the flow of people and materiel throughout the theater of operations. The authors designed a three-hour training curriculum around a microworld model that represents a simplified, but dynamic, model of the distribution management process. The main goal of the session was to teach the learners about the consequences of their decisions over time and across the distribution management system. Participants in the microworld-based training sessions improved significantly in their ability to identify problematic trends in a distribution network and to evaluate the impacts of those trends.

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